PHYSICS JANUARY 1988 VOL. 41 NO. 1

PHYSICS JANUARY 1988 VOL. 41 NO. 1

titanic collision of a Mars-sized planetesimal with the proto-Earth sometime in the first 100 million years of solar system history.⁵

It is not my intention to discuss these fascinating topics, however, but to point out that in conjuction with ongoing work on them there has been much fundamental progress in the understanding of impact cratering physics. This includes computation, theory, and experiment. The application of this new and evolving understanding promises not only greater insight into the events mentioned above, but to the general problem of how the solar system was assembled.

Impact cratering, unlike nearly any other geophysical phenomenon, involves a very broad range of mass, length, and time scales, each with a rich physics. This makes any analytical theoretical description of the process approximate in one regard or another. The advent of economical, highspeed computation promises to transform our knowledge of cratering aspects that are inaccessible to experiment. These include large-scale impacts, the growth of craters to socalled late times, and cratering of complex and novel targets. Calculations have now been carried out from early to late times. 6.7 The modification stage of large cratering events, in particular the transition from transient cavity expansion to gravity-driven rebound of the crater floor, has been observed. Such rebounds have been inferred from field data and analytical models, but interpretation or even existence of crater rebound has remained controversial in the planetary geology community. This work illuminates the physics of the origin of flat crater floors (as opposed to simple bowl shapes), central peaks within them, and multiple-ring mountains seen around the largest craters on the Moon and other planetary bodies.

Code calculations also allow effects of complex target geometries to be explored. A water layer overlying a rock halfspace (for simulating impact into the Earth's ocean) is an obvious example. Less obvious is "cratering" of the Earth's atmosphere. Here the vertical pressure and density structure and (in some cases) the Earth's sphericity render the "target" complex. The role of impact in accretion and ablation of the Earth's primordial atmosphere (and those of other solid planets and satellites) is just beginning to be modeled.

Our ability to interpret the results of large code calculations, high-explosive field trials, and laboratory-scale experiments has also greatly improved owing to greater comprehension of scaling. Because many cratering phenomena occur at scales much larger than the impactor, it can be replaced by an equivalent point source of energy and momentum. Older energy-scaling rules are thus revised. While it is premature to declare this new scaling complete, it has proved remarkably successful. For instance, extrapolation from laboratory impact experiments in water is accurate for both 19th-century water-drop experiments and code calculations of multimegaton explosions in water.

Experimental support for the theories comes mainly through the use of centrifuges to simulate greater physical scales by means of elevated gravity. Also novel experimental situations continue to pose theoretical challenges, among them cluster (or dispersed) impactors, impact vaporization, and spallation and whole-target fragmentation.

Much further progress and unexpected discoveries and applications are anticipated. One example is the issue of solar system bombardment history. Untangling the role of comets, asteroids, and circumplanetary debris in cratering the various satellites and planets may disentangle the collisional and dynamical evolution of these small-body populations and the relative/absolute chronologies of planetary surface processes. In turn, we may thus work, step by step, back through the history of accretion of the planets. 11-13

William B. McKinnon, Washington University

- Geological Implications of Impacts of Large Asteroids and Comets on the Earth, edited by L. T. Silver, and P. H. Schultz, Geol. Soc. Am. Spec. Paper 190 (1982).
- 2. L. W. Alvarez, Phys. Today 40, 24 (July 1987).
- 3. D. Bogard, guest editor, Geophys. Res. Lett. 10, 773 (1983).
- 4. H. J. Melosh, Geology 13, 144 (1985).
- Origin of the Moon, edited by W. K. Hartmann, R. J. Phillips, and G. J. Taylor (Lunar & Planetary Institute, Houston, 1986).
- 6. T. J. Ahrens and J. D. O'Keefe, Int. J. Impact Eng. 5, 13 (1987).
- D. J. Roddy, S. H. Schuster, M. Rosenblatt, L. B. Grant, P. J. Hassig, and K. N. Kreyenhagen, Int. J. Impact Eng. 5, 525 (1987).
- 8. K. A. Holsapple and R. M. Schmidt, J. Geophys. Res. 97, 6350 (1987).
- 9. P. H. Schultz and D. E. Gault, J. Geophys. Res. 90, 3701 (1985).
- D. R. Davis, P. Farinella, P. Paolicchi, and V. Zappala, Mem. S. A. It. 57, 7 (1986).
- C. R. Chapman and W. B. McKinnon, Satellites, edited by J. A. Burns and M. S. Matthews (University of Arizona Press, Tuscon, 1986), pp. 492-580.
- 12. R. G. Strom, Icarus 70, 517 (1987).
- 13. EOS Trans., AGU 68, 343 (1987).

Plate Tectonic Prediction Fulfilled

Why, according to a recent survey, do 81% of Americans believe the Earth's surface to be covered by moving tectonic plates, when only 47% accept the notion that humans are descended from more primitive animals? Apparently many of those skeptical of the geologic record of life are convinced by the evidence for past production and consumption of the Earth's surface. Both plate tectonics and natural selection are theories of slow change that depend on a reading of the geologic record for their principal support. Evolution, however, has been subject to much longer public and scientific debate. Charles Darwin published *The Origin of Species* in 1859. Fifty-six years later Alfred Wegener proposed, in *The Origin of Continents and Oceans*, that the continents drifted around the globe.

The leap from Wegener's hypothesis to plate tectonics, in which the continents are envisioned as moving with the sea

titume collision of a Mars-sized planetesimal with the proto-Earth sepretime in the first 100 million years of solar system history.*

It is not my intention to discous these fascinating topics, however, but to point out that in conjuction with ongoing work on them there has been much fundamental progress in the understanding of impact concering physics. This includes computation, theory, and experiment. The application of this new and evolving understanding promises not only greater insight into the events mentioned above, but to the general problem of how the solar system was assembled.

Impact crarering, unlike nearly any other guestysical phenomena, hivolves a very broad range of mass, beagin, and fand seales, such with a visit physics. This makes any analytical theoretical description of the process approximate in one regard or another. The advent of economical, high-speed computation promises to transform our knowledge of craftering aspects that are inaccessible to experiment. These include large-scale iropaets, the growth of craters to so include large-scale iropaets, the growth of craters to so called late times, and cratering of complex and novel targets funds have most from surely to late times. The modification make of large cratering events, in limes. The modification make of large cratering events in particular the transition from transient cavity exputation to particular the transition from transient cavity exputation to an according of the crater rebound into remained controlvenial in the plans and analystical models, but interpretation or even existence of the origin of this crater floors in separation or even existence duty goalogy community. This work illuminates the plansed of the origin of this crater floors in separation the planse when along a contral peaks without them, and multiple-ring mountains seen around the largest craters on the Moon and other glameners bedies.

Code calculations also allow effects of complex target greenerium to be explored. A water layer overlying a reck halfspace (for simulating impact into the forth's occasi) is halfspace (for simulating impact into the forth's occasi) is an obvious example. Less obvious is "containag" of the Earth's atmosphere. Here the vertical pressure and density render alreadure and (as some cases) the Earth's aphericity render the "target" complex. The only of impact in accretion and ablances of the Earth's primordial atmosphery (and those of other solid planers and satellites) is test toginaling to be modeled.

Our ability is interpret the results of large onde calculations, high-explusive field trude, and laboratory scale experiments has also greatly unproved owing to greater comprebunction of scaling. Because onesy entering phenomena occur at scales much targer than the impactor, it can be replaced by an equivalent point source of energy and ammention. Older energy-scaling rates are thus revised. While it is presentance to declare this new scaling complete, it has preved remarkably successful for instance, extrapolation from laboratory impact experiments in water is accurate for both 19th-century water-sloop experiments and code calculations of multipresent an evaluation and code calcu-

Experimental support for the theorist comes mainly through the use of centraluga to simulate greater physical states by means of elevated gravity. Also found experimental situations continue to pose theoretical challenges, among them cluster (or dispersed) impactors, impact supports.

Much further progress and imagested discoveries and applications are ambiguited. One complete the more of solar system hombardment limitory. Unturquing the rule of
lar system hombardment limitory. Unturquing the rule of
comets, asteroids, and circumplanetary differs in createring
the various satellites and planets may discountly the collicount and dynamical evolution of these simil-body popular
tions and the exlative/absolute chronologies of planetary
antiact processes. In sure, we may thus work, step by step,
looses through the history of accretion of the planets.

Ones through the history of accretion of the planets.

William R. McKirston, Wickington University

- Conditional Department on Virginia of Large Attendant and Consults on the According to the L. T. Wilson, and P. M. Schiller, and Son, Ame. Spin. Preprint 1992 (1992).
 - THE ADDRESS OF THE PARTY OF THE PARTY.
 - 7. C. Degard, good willey, Complete Line Lock 10, 371 (1983).
 - A SECTION AND ADDRESS OF A PERSON.
- Chapte of the Apines, extend to W. M. Herrimann, M.J. Politique, and G. E. Toylor Change & Plantage Institute. Housing, 1986.
 - printed at the magnet A and observed A for the manufact A Total
- 7 St. J. Roghte, S. H. Schman, M. Rosselder, L. Bellema, P. J. Mannig, and K. M. Morganhagen, Ltd. J. Impact. Res. S. Sch. (1987).
- contracted by all colours to tames M. Marcolandell A. R. J.
 - V. P. D. Bittelly and D. R. Chell, J. Comput. Bandle, 1991, v1945).
- 13. D. Blook, F. Estimile, P. Pastinishi, and V. Zappala, Mrm. S. A. M.
- C. Chripmann and W. B. McChimon, Streether, minority L. S. Biggas and M. S. Martha et al. Distriction of Assistant Presid Tomore, (1981), pp. 492–493.
 - Charles and American Street, St. 51 St. 51
 - CONTRACTOR AND STORY

Plata Tectonic Prediction Fulfithd

Why, according to a accest survey, 'do & File of Agravicana bettern the Earth's surface to be covered bymossing textonic plates, when only \$7% accept the notion that humans are descended from some primitive minuted. Apparently many of those steptical of the geologic mound of the are-convenced by the estalance for past production and experience for past production and experience floth plate textonics and natural adection are theories of slow change that depend only according of the geologic recent for their protection augment. Evolution, however, has been subject to much langer pastile and exercising debate. Charles Derwin published The Course of Species in debate. Charles Derwin published The Course of Species in Corgin of Charless Derwin published The Course or and the charles derived mounted the clobe.

The leap from Wegener's hypothesis to plate temonics, in which the continents are envisioned as moving with the sea floor rather than plowing through it, followed in 1965. Until now, neither species evolution nor continental motion could be observed during a human lifetime, but plate tectonics is no longer a matter of geologic conjecture: During the past four years the movement of the Earth's dozen plates has been measured, centimeter by centimeter, across four continents and three oceans.

Because of the stately pace of the plates, which slide at rates of 1 to 10 cm/yr on a substrate of partially melted rock, detection of plate motion awaited measurements of intercontinental baselines accurate to several centimeters. Currently three independent techniques yield comparable plate velocities and directions.⁴

To measure the relative movement of plate interiors, reflectors were launched into Earth orbit and several groundmounted lasers were engaged in a three-dimensional positioning analogous to triangulation, called satellite laser ranging. During the past four years, observation of quasars-extragalactic radio sources emitting a random "universal bar code" that can be timed and cross-correlated between receivers-has given us the most precise method to gauge baselines spanning the girth of the Earth. This method, known as Very Long Baseline Interferometry (VLBI), has measured the relative motion of five of the Earth's plates to a precision of one part per billion.⁵ Finally, a growing constellation of military NAVSTAR satellites that broadcast their position to small mobile receivers (the Global Positioning System) now provides the most versatile method to measure baselines shorter than 500 km.

The space and terrestrial observations yield a stunning result: the plate rates measured during the past few years are—within the measurement uncertainty—identical to those deduced for the past several million years from the geologic record. This discovery attests to the fidelity of the geologic record of our planet's past. More important, it means that the gravitational forces that drive the plates and the viscous forces that resist their motion must stay balanced over millions of years. The jerk of occasional great earthquakes at plate edges, and the perhaps million year cycle of transient convection—eddies of flowing rock beneath the plates—may thus leave the plates unperturbed.

Ten million years ago the Pacific plate began to take a western sliver of California with it on its northward march toward Alaska, the cut now known as the San Andreas fault system. The faults provide our best opportunity to measure plate movement and deformation on land. The stick-and-slip motion along the uppermost 10 km of the faults accounts for California's plentiful supply of earthquakes (see Fig. 1). During the past two million years, just under 5 cm/yr of relative plate motion has been accommodated by slip along the San Andreas fault system. Displacement of ancient tributaries across the fault reveals that during the past 15,000 years, the central San Andreas has slipped an average of 3-4 cm/yr. Recent resurvey of century-old triangulation monuments installed by the U.S. Coast and Geodetic Survey to

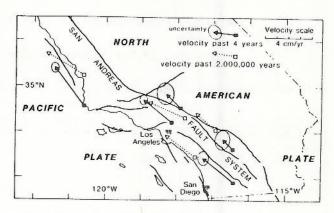


FIG. 1. Velocity vectors for the movement of the Pacific plate relative to the North American plate in southern California, deduced from four years of VLBI measurements (solid arrows) and from geologic rates of fault slip and sea-floor spreading (dotted arrows).

construct maps for the Gold Rush shipping traffic indicates a rate of at least 3.3 cm/yr during the past century.⁴ The most recent VLBI measurements yield a rate across the San Andreas system of 3–4 cm/yr.⁶ Thus a consistent picture of plate movement emerges on time scales sampled at 4, 100, 15,000 and 2,000,000 years.

The claim that we have finally measured the contemporary motion of continents oddly echoes one made prematurely by Alfred Wegener in 1929: "We begin the demonstration of our theory with the detection of present-day drift of the continents by repeated astronomical positioning, because only recently this method furnished the first real proof of the present-day displacement of Greenland-predicted by drift theory—and because it constitutes a quantitative corroboration."7 From repeated longitude measurements Wegener inferred that Greenland had drifted 1610 ± 285 m from Europe between 1827 and 1907, a rate of 19 ± 3 m/yr. This result agreed with longtitude observations performed elsewhere on Greenland between 1860 and 1921. Wegener dismissed the possibility-now known to be true-that gradual improvement of the measurement precision, rather than drift of Greenland, accounted for the longitude changes: "This accumulation of similar results which do not stand in opposition to any others makes it highly improbable that it is all just a matter of unfortunate combination of extreme errors of observation."7 Today, Wegener stands at once vindicated and discredited. Greenland is indeed drifting away from Europe, but at a velocity now measured to be 1.9 ± 1.0 cm/yr, one-thousandth Wegener's proffered rate.

It is ironic that plate tectonics enjoyed such widespread acceptance before this crucial confirmation, whereas evolution—read from the same geologic and fossil record—remains controversial. Our response to scientific advances appears to be bound more closely to how we view ourselves than it is to how we view the science. One cannot help but wonder whether confirmation of evolution, such as contemporary observation of speciation by natural selection, would encourage the reluctant 53% to acknowledge their simian

floor rather than plowing through it, followed in 1965. Until now, usiber species evolution my continued lawarion could be observed during a human lifetime, but plate tentonics is no longer a matter of geologic conjecture. During the past four years the movement of the Earth's dozen plates has been measured, continuerer by continuetes, notices four continuents and three occurs.

Because of the stately pace of the plates, which slide at rates of l ar 10 cm /yr on a substrate of partially medical rock, detection of plate motion awasted measurements of intercontinental baselines accurate to several continuous. Currently three independent techniques yield comparable plate veloctions and directions.

To measure the relative measurement of plate interiors, refluctors were faunched and Barth orbit and several groundmounted bases were engaged in a three-dimensional pastfloring analogous to triangulation, called satellite laser
floring analogous to triangulation, called satellite laser
floring During the past four years, observation of quasare—extragalactic radio scarces emitting a random "unitsare—extragalactic radio scarces emitting a random "unitwersal bar scole" that can be timed and cross-correlated between receivers—has given us the most precise method to
gauge baselines apanting the girth of the Earth. This mostgauge baselines apanting the girth of the Earth. This mostod, known as Very Long Baseline Interfacemetry (VLBI),
has measured the relative motion of fire of the Earth's plates
to a precision of one part per billion. Plually, a growing
constellation of colors and method to
cast their position to small metalal receivers (the Global Bostrioung System) new provides the most vermille method to
measure observant than 300 km.

The space and terrestrial observations yield a situating results the plate rates recessored during the past few years are within the uncantrement uncertainty—identical to these deduced for the past several million years from the geologic record. This discovery attests he the fidelity of the geologic record of our planet's past. More important, it means that the gravitational forces that drive the plates and the viscous lowes that tends their motion must stay balanced over millions of yours. The jerk of occasional great earthquakes at plate edges, and the perhaps million year cycle of transient convection—eddies of flowing rock beneath the clustes—may thus leave the plates unperturbed.

Test million years ago the Pacific plate began to take a sentern aliver of California with it on its northward manta toward Alaska, the cut now known at the San Austreas faight system. The faults provide our best apportunity to measure plate movement and deformation on land. The site's and-slip caption along the uppermont 10 km of the faults accounts for California's plentiful supply of earthquaken (see Fig. 1). During the past two million years, just under 5 can'ry of relative plate motion has been accommodated by slip along the San Andreas fault system. Displacement of succent tributaries across the fault reveals that during the past 13,000 butaries across the fault reveals that during the past 13,000 years, the course San Andreas has slipped an average of 3-a many. Recent resurvey of century-old triangulation monuments insuelled by the U.S. Coast and Goldenia Sances.



FIG. 1, Variously workers hat also recommend of the facility plate relatives on the bloom's Australia on From him years of Various Australia on From State State on From State State

construct maps for the Gold Roats shipping traffic sudicases a rate of at least \$2 maybe during the past century. The most recent VLBI measurements yield a rate across the San Andreas system of 3-4 cm/yr. Thus a consistent picture of plate acovernm converges on time scales sampled at 4, 100, 15,000 and 2,000 000 years.

racy enotion of continues oddly echogs one mode prematurely by Alfred Wegeney in 1829. We tegin the demonstration of our times with the detection of present-day drift
stration of our times with the detection of present-day drift
cause only recently this method familial the first ceal good
cause only recently this method familial the first ceal good
drift theory—and because it constitutes a quantitative corrodrift theory—and because it constitutes a quantitative corrodrift theory—and because it constitutes a quantitative corroboundary. From reported longitude measurements Wegener macrose that Greenland longitude defined: 1610 g 285 m
from Europe between 1827 and 1507, a rate of 18 g. 1 mayor
from Europe between 1827 and 1507, a rate of 18 g. 1 mayor
class the greenland between 1860 and 1921 Wegoner
distributed the preschiltry—now known to be true—that gendual improvement of the measurement preclaim, rather
than drift of Greenland, accounted for the hungitude
than drift of Greenland, accounted for the hungitude
changes (This measurement and similar tearlits which do not
than on all test a nature of unformate combination of exthat on all test a nature of unformate combination of exclass on all test a nature of unformate combination of exclass on all test a nature of unformate combination of exclass via themse strong of observation. The day, Wegener mands at
come via themse terrors of observation. The observation is not extended driftcase way from Europe, but at a venezity new measurest to be
constructed from the observation of the process of the content of the content of the process of the content of the con

It is ironic that plate factories enjoyed such waterpread acceptance before this crucial confirmation, whereas evolution—read from the same protogic and front record—remains controversial. Our response to audientific advances appears to be bound more closely to however view cursaives than it is to how we view use science One cannot help but woulder whether confirmation of evolution, such as contemporary observation of epociation by marrial extention, would execution, would execution, would execution, would

past. Or is a mobile planetary shell somehow less fantastic than the transmutation of life?

Ross S. Stein, U.S. Geological Survey

- I. J. D. Miller, Am. Demographics 9 (6), 26 (1987).
- C. Darwin, The Origin of Species, repr. of 1st ed. (Philosophical Library, 1951).
- A. Wegener, Die Enstehung der Kontinente und Ozeane (Sammlung Vieweg, Braunschweig, 1915), Vol 23, p. 94.
- 4. R. S. Stein, Rev. Geophys. 25, 855 (1987).
- 5. W. E. Carter and D. S. Robertson, Sci. Am. 255, 46 (1986).
- 6. P. M. Kroger, G. A. Lyzenga, K. S. Wallace, J. M. Davidson, J. Geophys. Res. (in press, 1987).
- A. Wegener, The Origin of Continents and Oceans, J. Biram translation of 4th (1929) ed. (Dover, New York, 1966), p. 23.

Dynamics of the Upper Ocean

The atmosphere presents an almost constantly changing heat flux and wind stress to the surface of the sea. Recent field and theoretical studies have given a greatly improved description of the upper ocean's response to this surface forcing, and here we note some advances in understanding the effects of heating by solar insolation.

Much of the recent progress can be traced directly to new measurement techniques which have yielded field data sets with expanded duration and resolution. Notably, recent turbulence measurements from the equatorial Pacific Ocean show a pronounced diurnal cycle of upper ocean turbulence.2-4 The immediate effect of solar heating is to produce a warm layer adjacent to the sea surface. The static stability of this layer inhibits the downward penetration of turbulent vertical mixing so that the surface flux of heat and momentum will be trapped near the sea surface during mid-day. After the sun sets, sea surface cooling by evaporation and infrared radiation produces an unstable heat flux, and the resulting free convection and turbulent mixing by the wind then penetrates to surprisingly large depths, up to about 100 m. This great penetration of nocturnal mixing may be connected with the presence along the equator of strong, highly sheared mean currents which at some depths flow against the prevailing wind, but other hypotheses involving internal wave generation and re-absorption at depth appear equally plausible.5

Field observations from mid-latitude sites show that this solar heating-induced variation in mixing depth imposes a diurnal pulse on the wind-driven velocity. During mid-day the momentum flux supplied by wind stress is absorbed within the warm surface layer which then accelerates downwind as a diurnal jet. The Coriolis acceleration due to the Earth's rotation turns the diurnal jet clockwise during the day (northern hemisphere) and by sunset the jet may be turned counter to the wind. During the remainder of the night the adverse wind stress together with the increased vertical mixing will often erase completely the diurnal jet generated during the preceding day. The long-term average of this diurnally pulsing current has a spiral shape. These

solar heating plays by modulating the penetration depth of vertical mixing.

Satellite-derived infrared views of the sea surface reveal the large scale patterns of diurnal warming. In many cases there is a remarkably clear signature of the overlying surface heat flux and wind stress. For example, large amplitude diurnal warming of up to 3 C occurs along the axis of marine high pressure systems where there is a coincidence of clear sky and light winds. In the future it may be possible to exploit this new knowledge of the effects of solar heating to infer meteorological data in remote oceanic regions which are inaccessible to direct observations.

James F. Price, Woods Hole Oceanographic Institution

- J. F. Price, E. A. Terray, and R. A. Weller, Rev. Geophys. Space Phys. 21, 193 (1987)
- M. C. Gregg, H. Peters, J. C. Wesson, M. S. Oakey, and T. J. Shay, Nature 318, 140 (1985).
- 3. J. N. Moum and D. R. Caldwell, Science 230, 315 (1985).
- J. N. Moum, T. R. Osborn, and W. R. Crawford, J. Phys. Oceanogr. 16, 1516 (1986).
- 5. C. C. Eriksen and E. J. Katz, Rev. Geophys. Space Phys. 21, 217 (1987).
- J. F. Price, R. A. Weller, and R. Pinkel, J. Geophys. Res. 91, 8411 (1986).
- L. Stramma, P. Cornillon, R. A. Weller, J. F. Price, and M. G. Briscoe, J. Phys. Oceanogr. 16, 827 (1986).

High-Pressure Experiments and the Earth's Deep Interior

What is the nature of the Earth's core? How high is the temperature at the center of our planet? Advances in high-pressure experimental techniques are yielding new insights about the deep interior, revealing that the core is an unusual alloy of iron with a peak temperature exceeding that of the sun's surface.^{1,2}

The experimental breakthroughs allow materials to be examined in detail at the extreme conditions of the core: pressures ranging from 136 GPa (billion Pascals) at the core-mantle boundary to 364 GPa at the center (1.36 to 3.64 million times atmospheric pressure) and temperatures above 3500 K. The most recent developments involve a laser-heated diamond cell, in which less than one microgram of sample is squeezed between the points of two gem-quality diamonds. Pressures in excess of 500 GPa have beeen achieved by this technique.3,4 To simulate deep-Earth temperatures a laser beam is focused through the diamonds and into the sample area, thus producing temperatures of 1000-7000 K.5.6 During the experiments the sample is directly observed through the diamond anvils (or more properly in this context, the diamond windows) by techniques ranging from x-ray diffraction to visible and infrared spectroscopy. In particular, temperature is determined by spectroradiometry. Complementing the diamond cell, in which high temperatures and pressures can be sustained for hour-long periods, are the well-established shock-wave experiments

past. Or is a mobile planerary shed nomebow less furnamedian that transmission of life?

Ross S. Smitt, U.S. Geological Survey

- A. J. D. Affilia Ann. Democratical Village Science (1981).
- C. Direcca. The Gregor of Species, repr. of Let ed. (Philosophical Letters), 1931.
- P. A. Wagner, Die Steinbarg die Sanderme und Gemie Gleinerland
 - W. H. N. Stein, Rev. Georgiese, 25, 557 c rively.
 - A. W. E. Christman D. S. Kotsomon, Sci. Acc., 285, 487 (1996).
- & P. M. Karque, G. A. Lovings, K. S. Wattern, A. M. Christman, A. Constigue, New (in press, 1987)
- J. Wegener, The Origin of Control Course, J. Elevanteral and Course, J. Elevanteral and St. (1919), pp. 23.

Dynamics of the Upper Ocean

The armiciphere presents an almost constantly changing bear flux and wind three to the surface of the sea, Recent field and theoretical studies have given a greatly (reproved description of the appear occasi's response to this sai face factoring, and here we must some advances in understanding the offects of hearing by soiar regulation."

Much of the recent progress can be traced directly to meameasurement techniques which have yielded licid data only
with expanded duration and resultation. Notably, recent turbalence measurements from the equacional Pacific Ocean
show a groupmond diagrant cycle of apper conta turbushow a groupmond diagrant cycle of apper conta turbushow a groupmond diagrant cycle of some lending as to produce these.

The immediate effect of some lending as to produce this layer ministers at the downward penetration of narbalent
this layer ministes the downward penetration of narbalent
tractions in the surface flux of heat and somenrestrict mixing so that the surface down of heat and somenturn will be trapped mear the surface cooling by evaporation and
affer the and sets, see surface cooling by evaporation and
infraced rectains produced an westable heat flux, and the
resulting free convention and turisdent mixing by the wind
than penetrates to surprisingly impending may be exputhen penetrates to surprising the equator of except light
method with the presence along the equator of except legitly
the presenting wind, but other hypotheses involving internal
the personal of the discorption at depth appear equally
wave generation and remiscorption at depth appear equally

First observations from models ages show that this solar heating enduced variances in reacing depth imposes a cliurnal pulse on the wind-driven velocity. During cold-slay the manuscript flux supplied by wind stress is absorbed within the warm methace layer which then accelerates downwind as a churnal jet. The Coriolis acceleration that to the Earth's rotation turns the diarnal jet clockwise during the day (northern hemisphere) and by sunset the jet may be turned examples wind. During the remainder of the remainder with the increased night the adverse wind stress angether with the increased vertical mixing will often cross completely the diarnal jet generated during the proceding day. The long-term average generated during the proceding day. The long-term average.

solar hearing plays by modulating the penetrarius depth of

Sacalitecherised infrared sugas of the fee surface rescal the large scale participy of distinal warracing. In many cases there is a remarkably clear signature of theoremisting surface has a fact and warracing of up to 3 C counts along the axis of marine distinal warraing of up to 3 C counts along the axis of marine high pressure spatems where there is a collectence of clear sky and high wants. In the functor it may be possible to exploit this new knowledge of the effects of solar heating to make metagonal data in remote occurre regions which are macrossible to direct outgrations.

James F. Price, Woods Hale Oceanigraphic Jacobins

- R. of Percent A. Terray, and R. A. Watter, Star Couldn'te Space Phys. 21, 1982 (1982).
- S. M. C. Dregg, H. Pener, L. C. Warrer, M. S. Oblag, and T. J. Stag.
- A. J. P. Alemin, T. R. Gilbory, and W. R. Comellint, E. Dige Assumings, 33, 1916, p. 1916, p.
- There has it said made relacible will and I I has small by I I
- This is not entered to below it was notice A it will be a limit;
- L. Stramma, P. Cargurina, V. A. Welfler, J. P. Petrophura M. G. Bromer, J. Phys. Commun. 16, 127 (1935).

High Pressure Experiments and the Earth's Deep interfor

What is the nature of the Earth's core? How high is the home personner at the center of our planes? Advances in high pressure experimental mehanispies are yielding new maintax about the deep interior, resculing that the core who unusual alloy of iron with a peak temperature exceeding that of the aun's unface.

The experimental breakthroughs allow materials to be examined in detail or the extreme conditions of the correpressions rouging from 136 GPa (billion Pascuts) at the concernantic boundary to 564 GPa at the copter (1.36 to 3.64 million manual monay manual pressure) and temperatures million manual minor count developments involve a lamperatured dismond cell, in which icse that one miorogram of sample is equivated dismond cell, in which icse that one miorogram of sample is equivated between the prints of two gen-quality dismonds. Presides in excess of 200 GPa have been achieved by this technique. To manulate likep-Barth temperatures a lasar beaut is focused through the dismonds and permitted area, thus producing temperatures of 1000—1000. The context, the diament arvise temperatures of 1000—1000 of the context, the diament arvise (or more properly in this context, the diament windows) by individual presentation from x-ray diffraction to visible and infrared spectroscopy. In particular, temperature is determined by spectrorality mistry. Complementation to visible and infrared spectroscopy paratures and pressures can be sustained for hour-long periods, are the well-established shock-wave experiments.